

FIG. 1

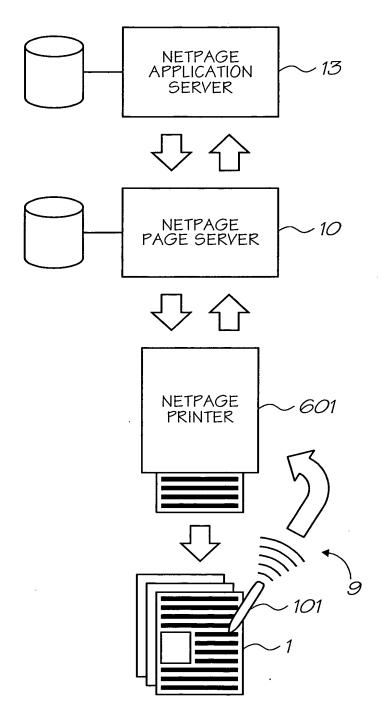


FIG. 2

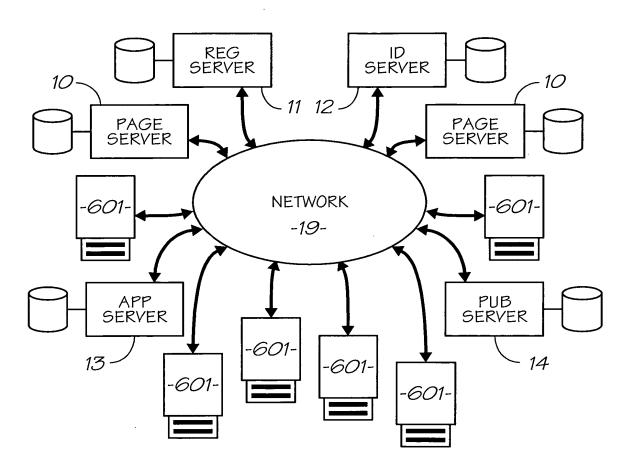


FIG. 3

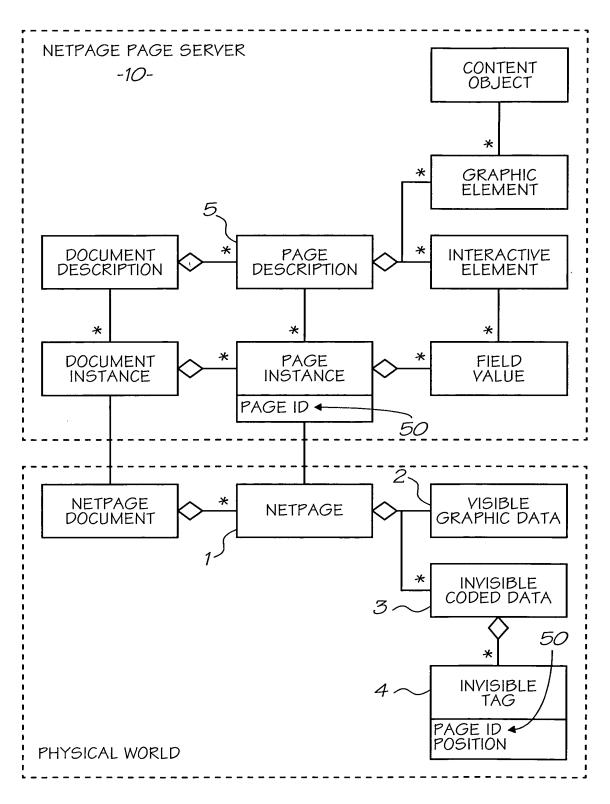


FIG. 4

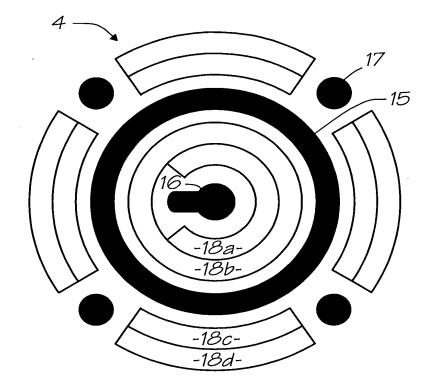


FIG. 5

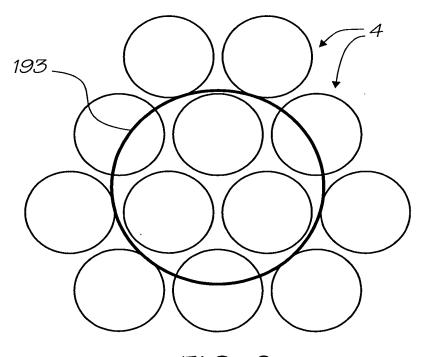
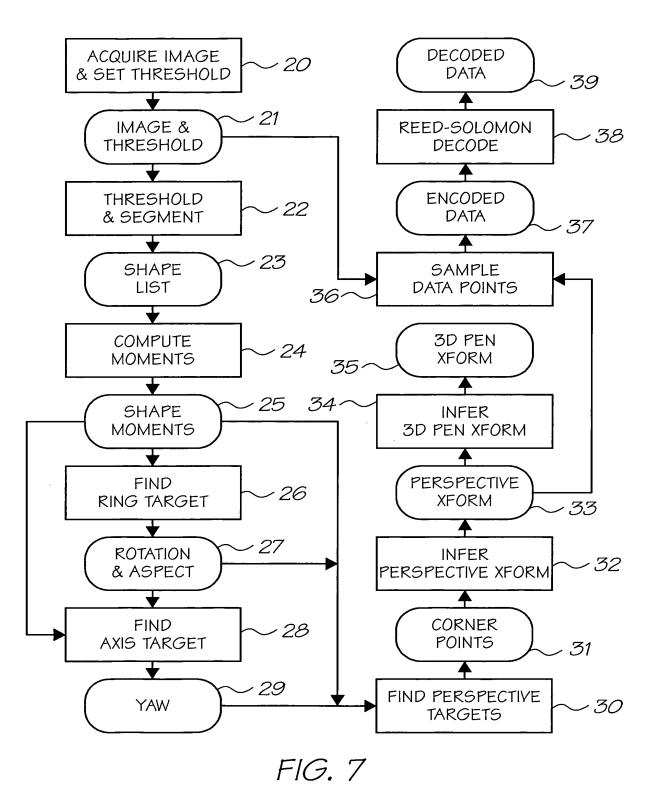


FIG. 6



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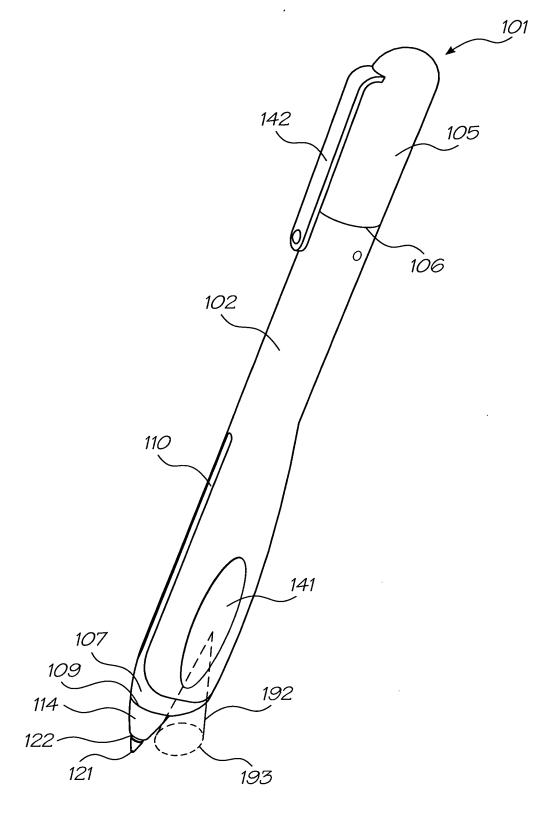


FIG. 8

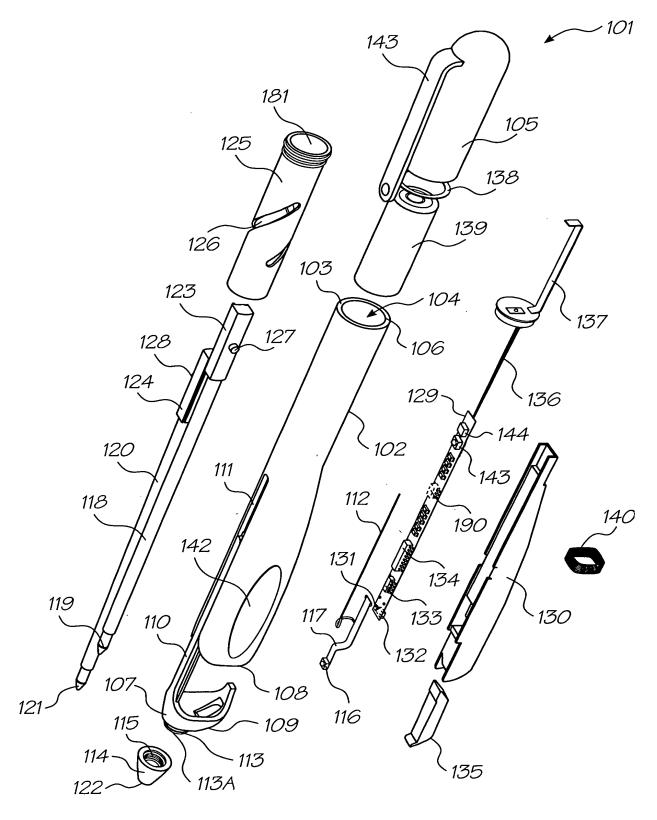


FIG. 9

FIG. 10

SENSOR

FORCE SENSOR IR LED

> ILLUMINATION IR LED

> TRI-COLOR STATUS LED

215×215 CCD IMAGE SENSOR

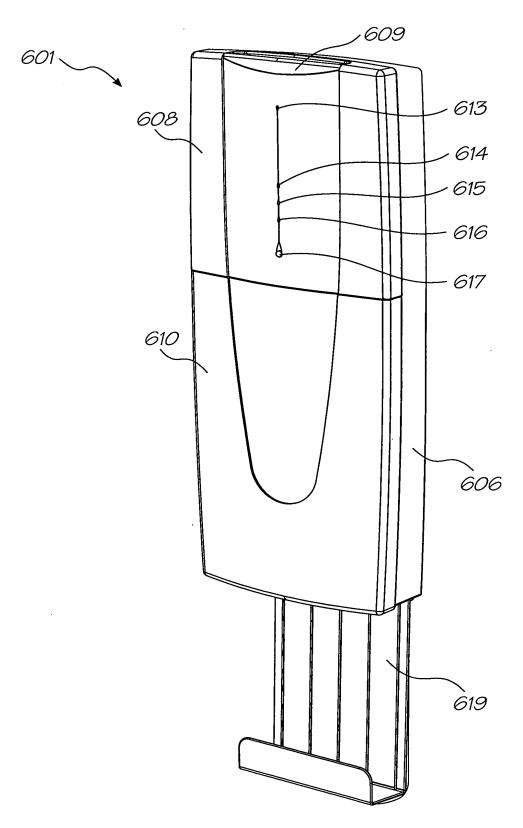


FIG. 11

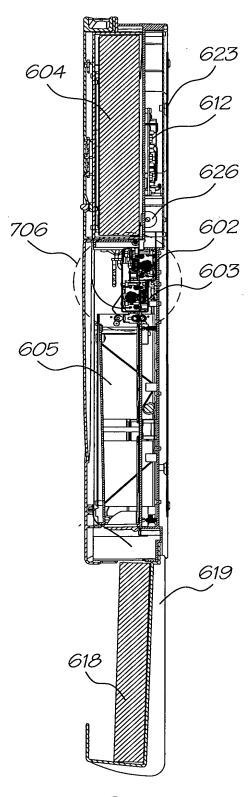


FIG. 12

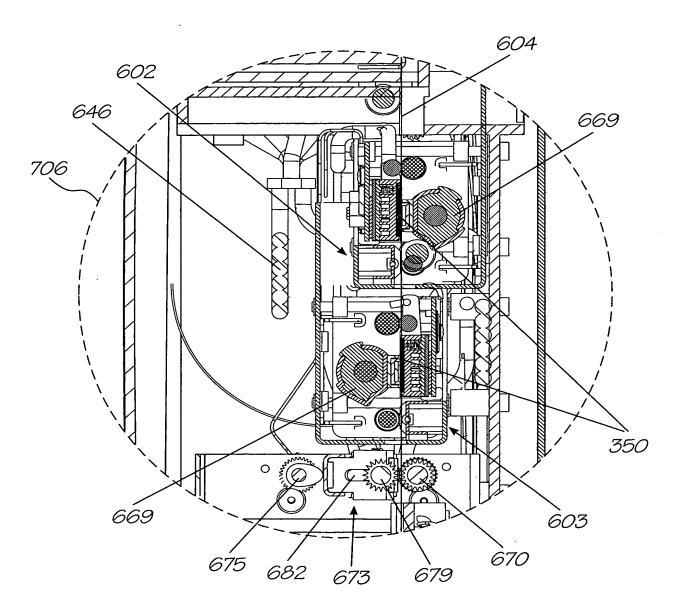


FIG. 12a

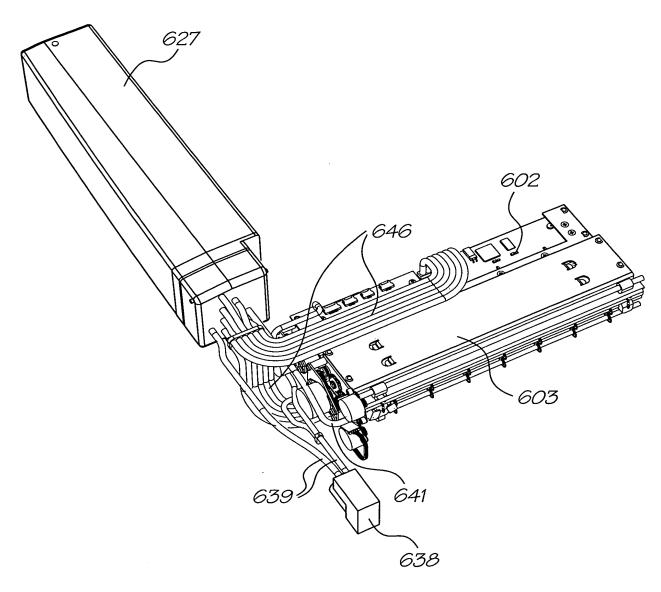


FIG. 13

COSTALES OSESOS

FIG. 14

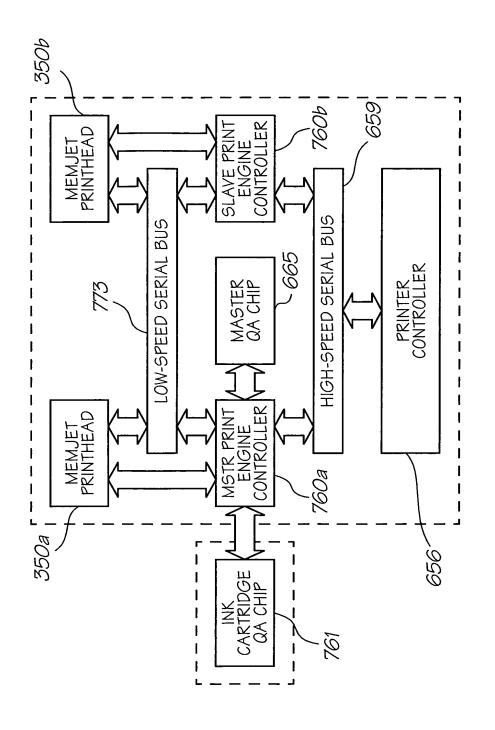


FIG. 15

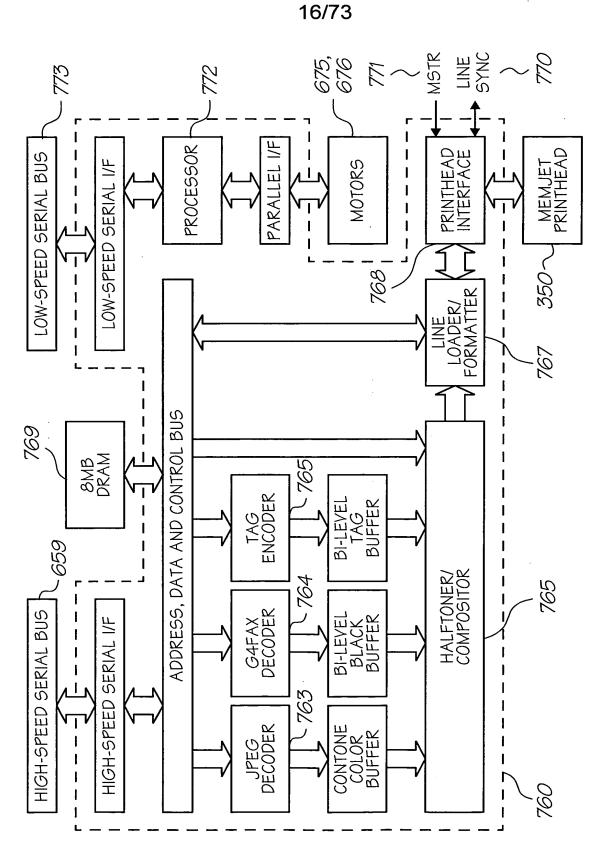


FIG. 16

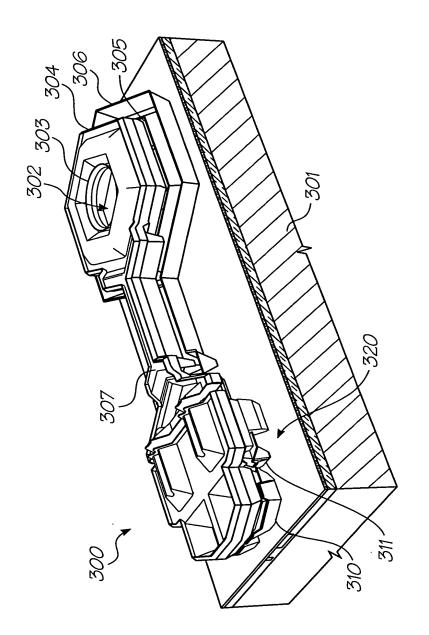


FIG. 17

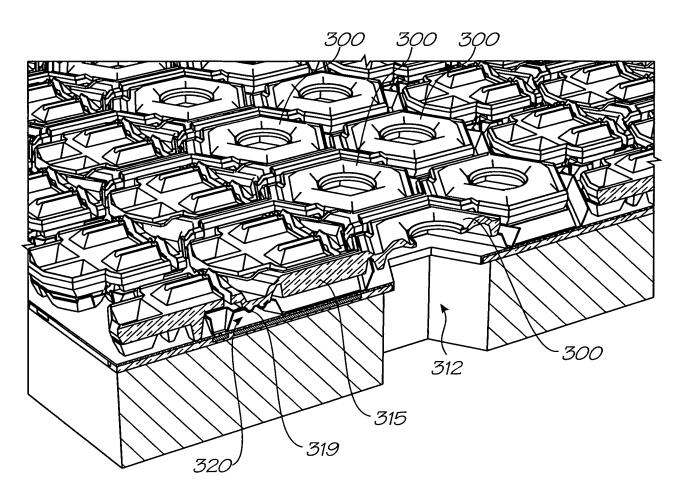


FIG. 18

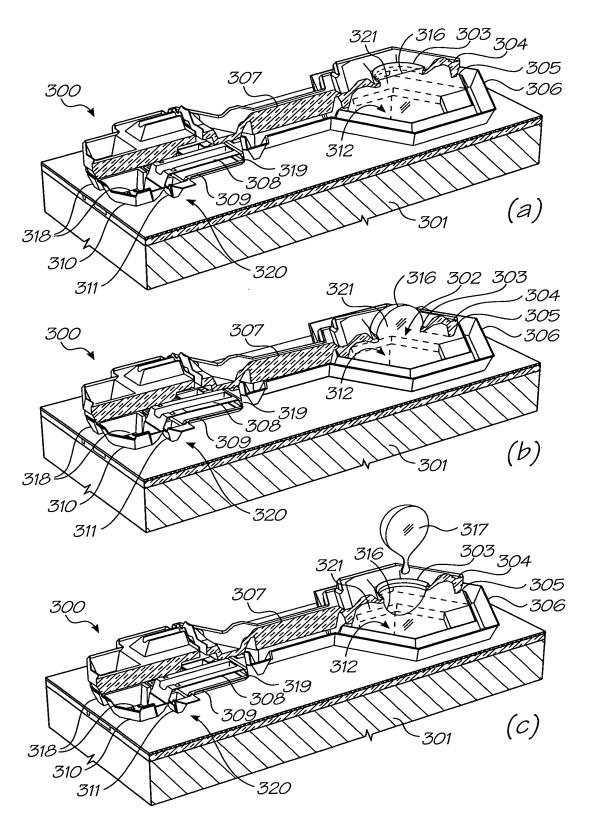
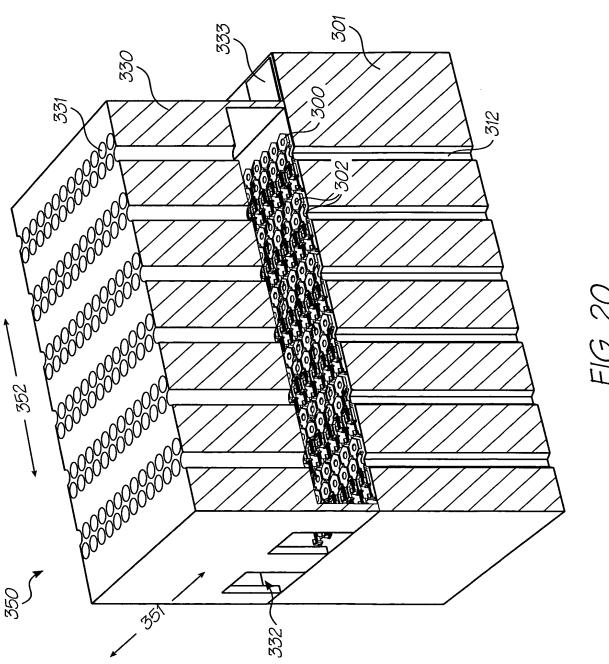


FIG. 19



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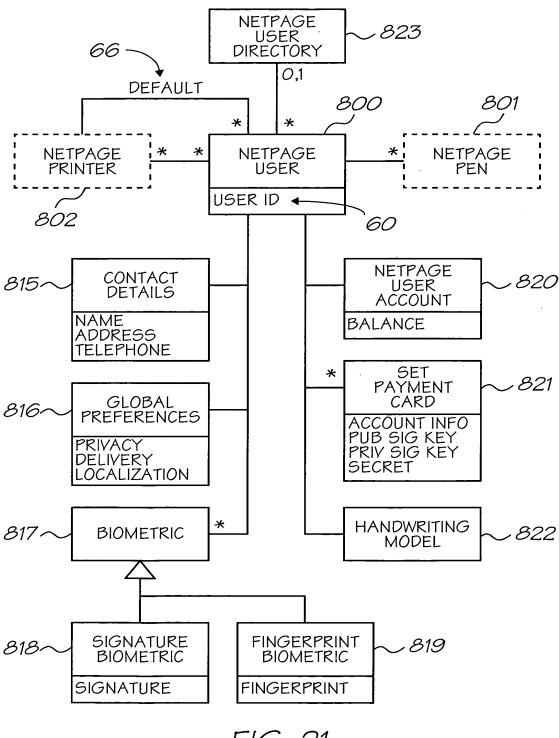
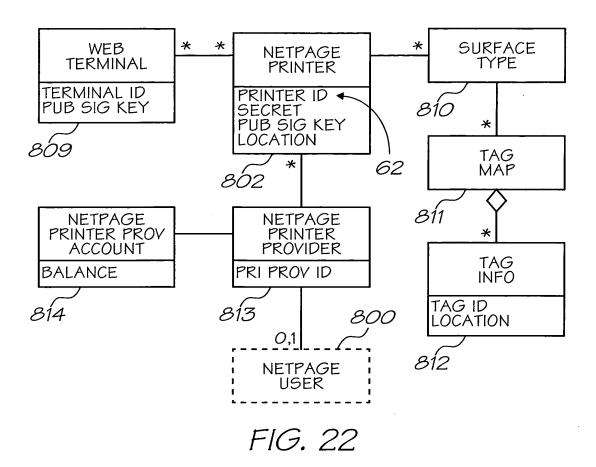


FIG. 21



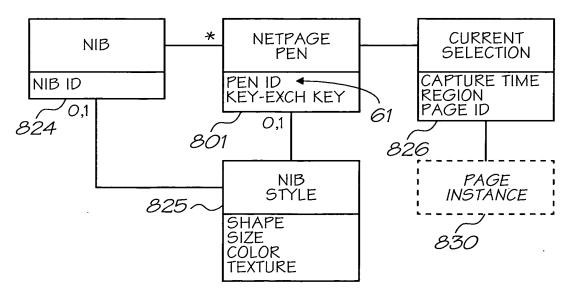


FIG. 23

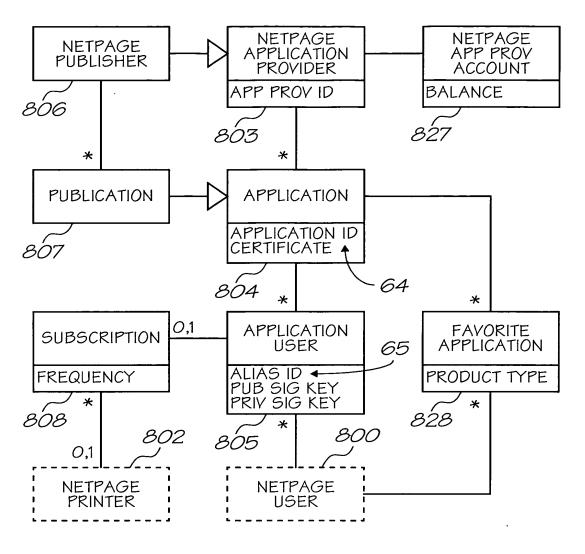
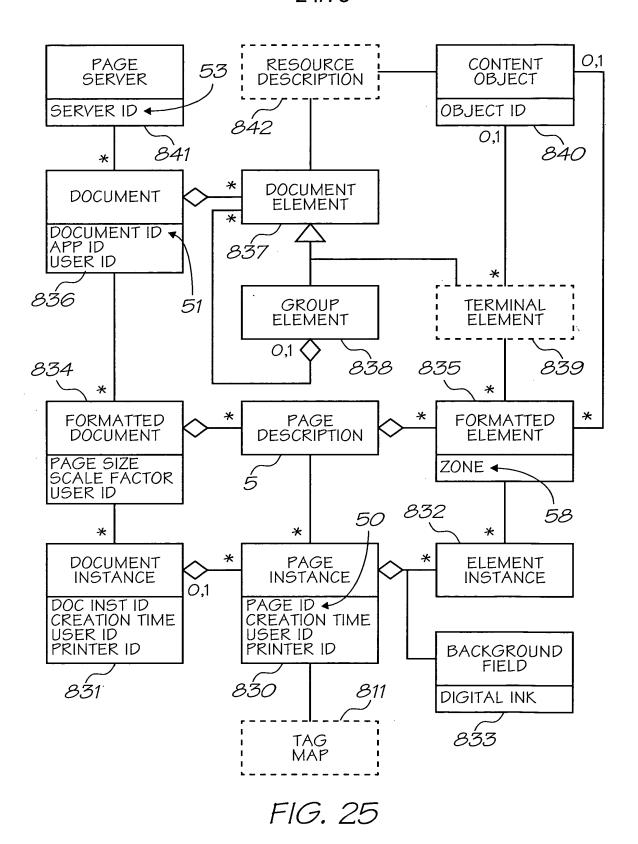


FIG. 24



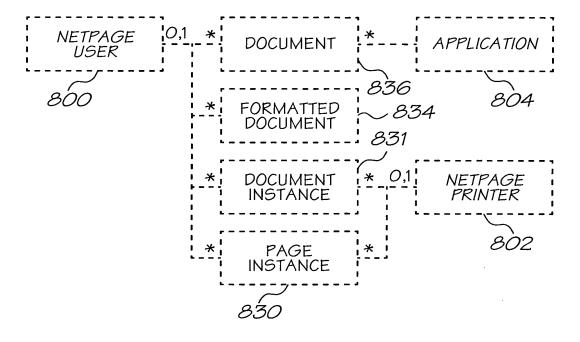


FIG. 26

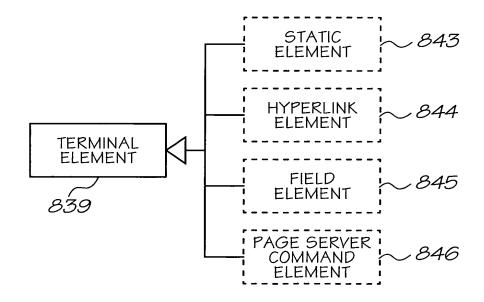


FIG. 27

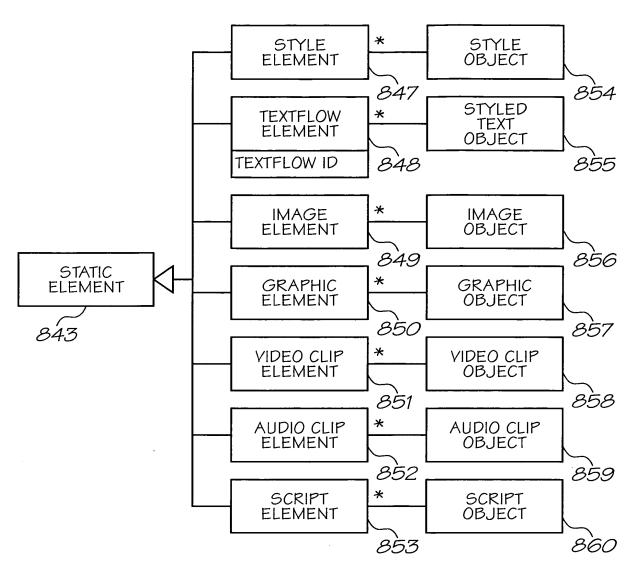


FIG. 28

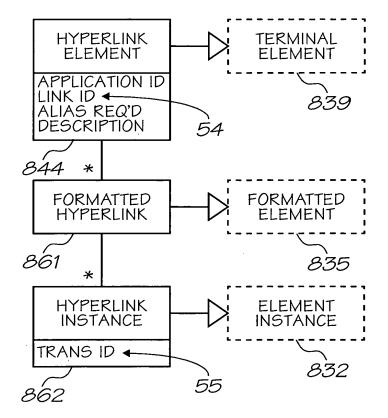


FIG. 29

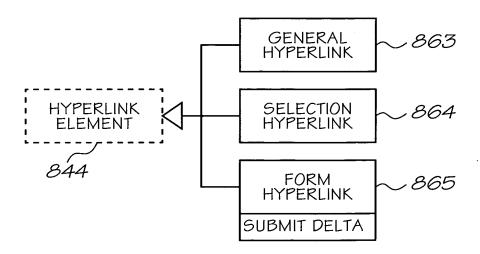


FIG. 30



FIG. 31

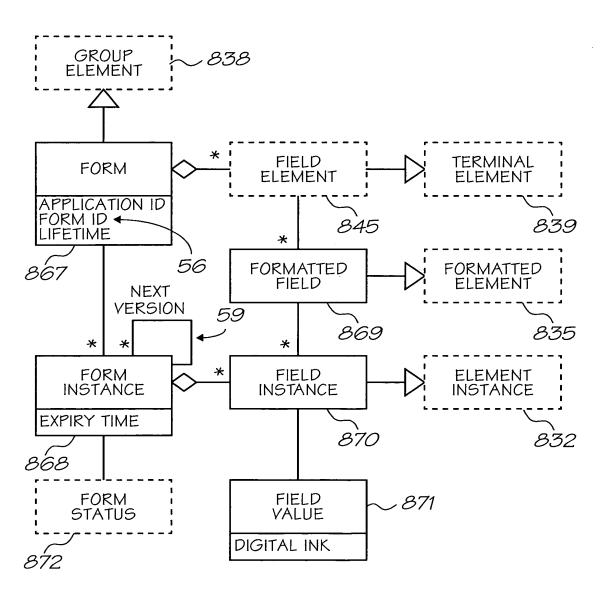


FIG. 32

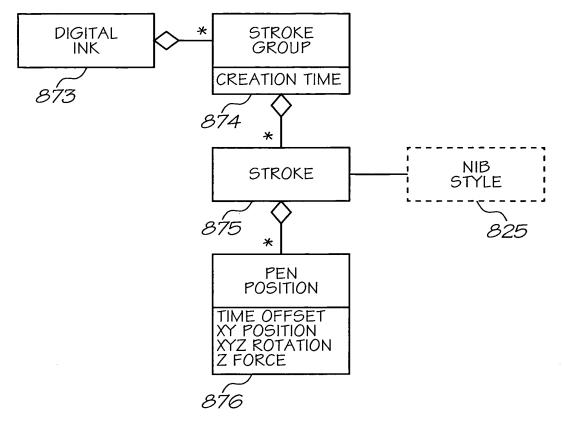


FIG. 33

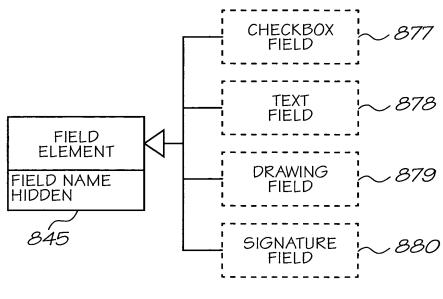


FIG. 34

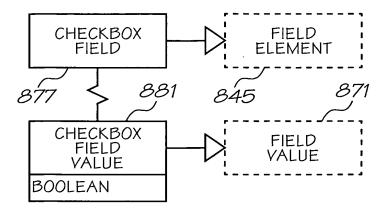
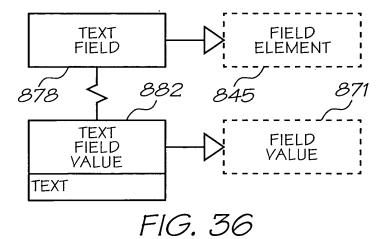


FIG. 35



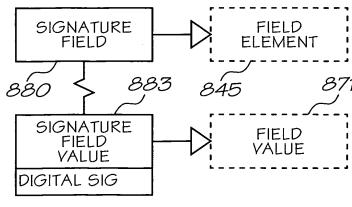


FIG. 37

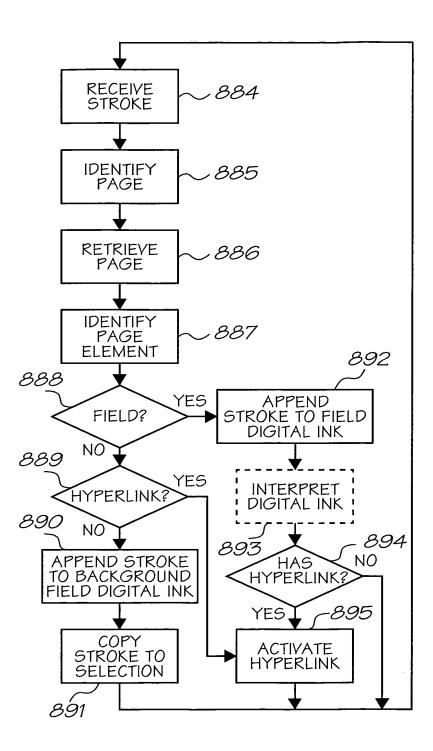


FIG. 38

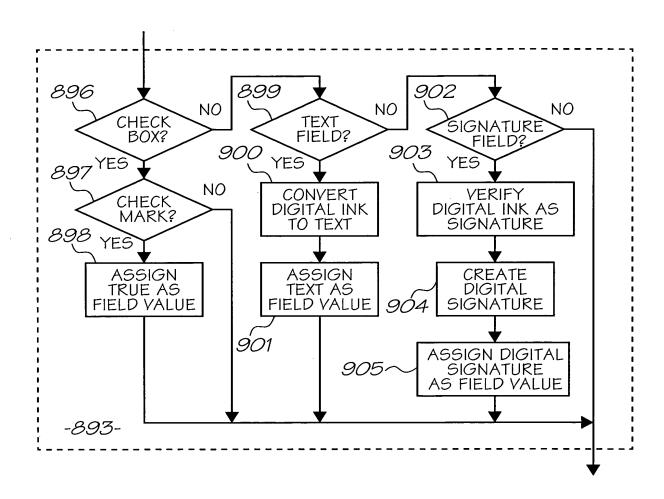


FIG. 38a

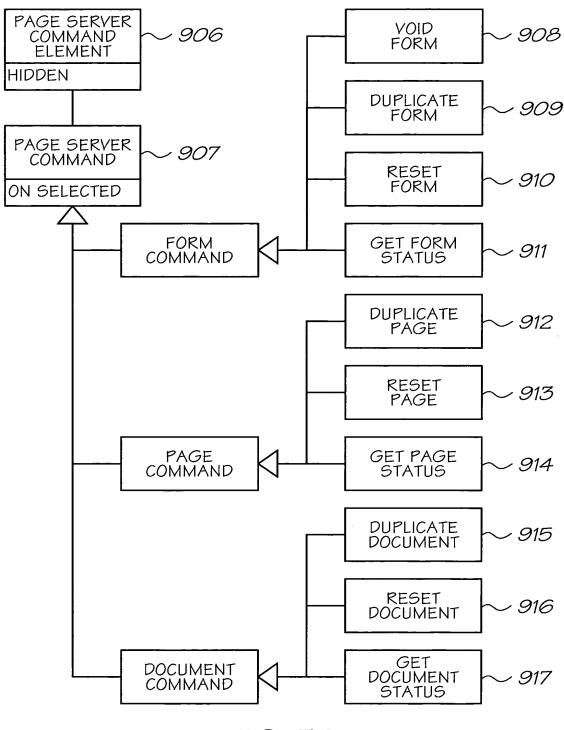


FIG. 39

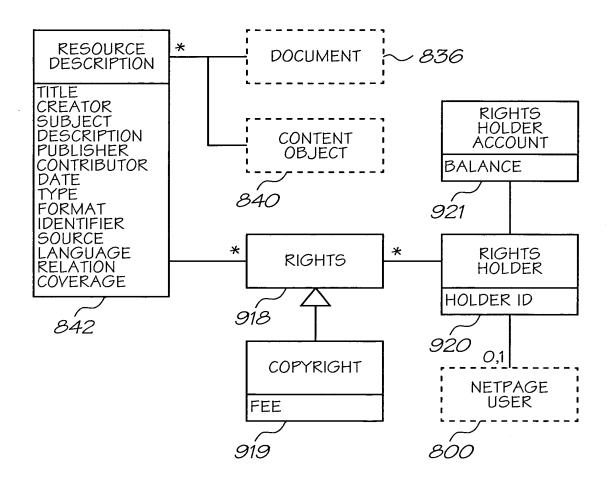


FIG. 40

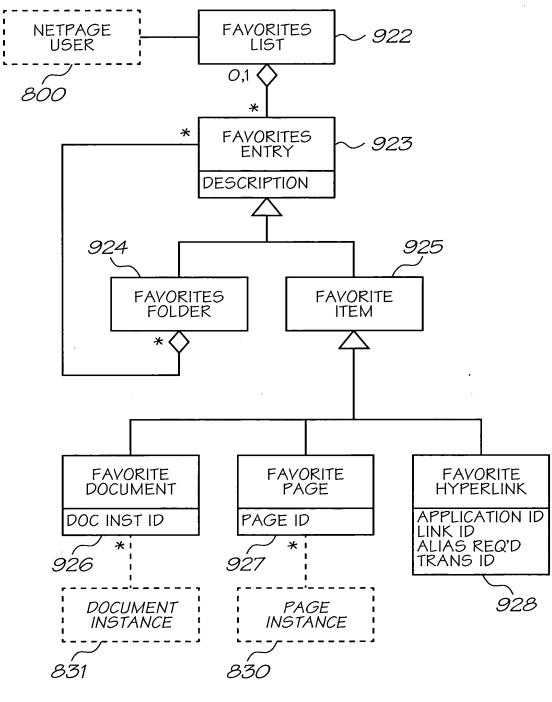


FIG. 41

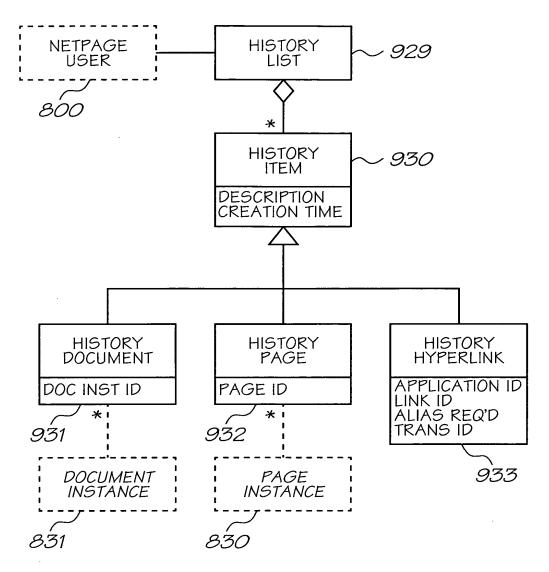


FIG. 42

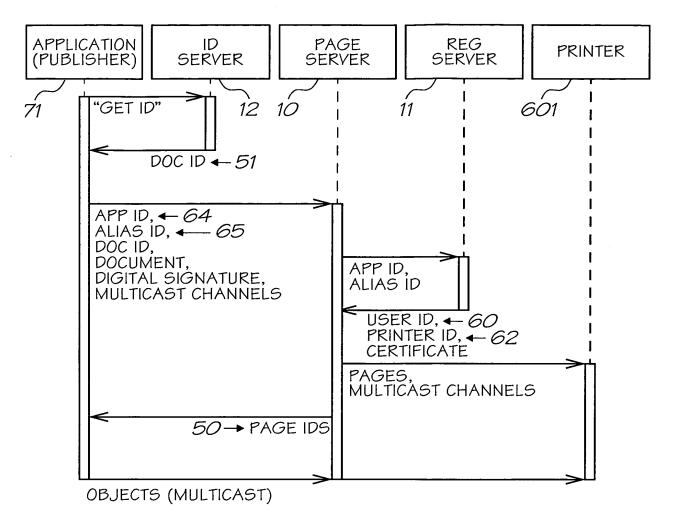


FIG. 43

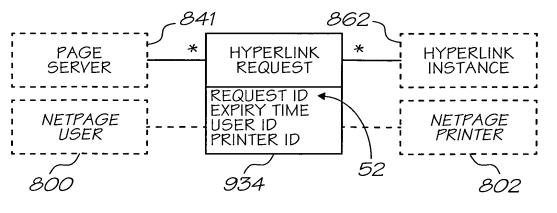


FIG. 44

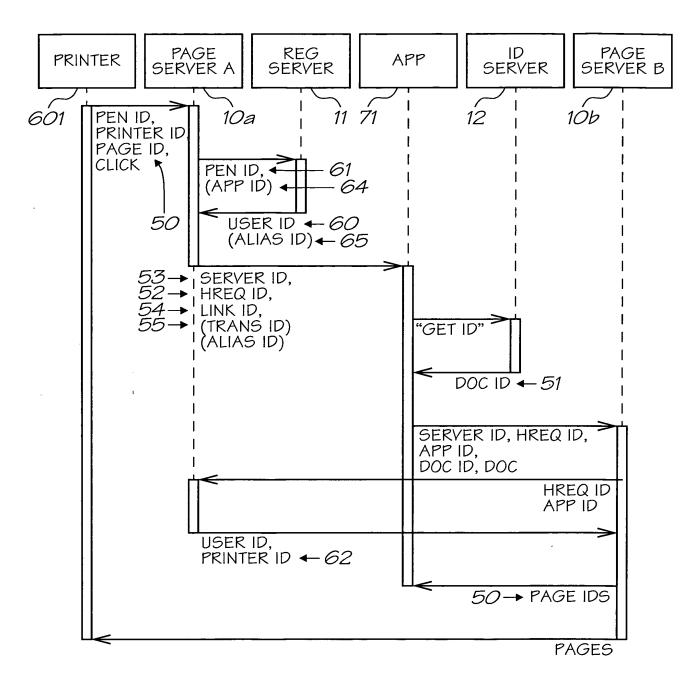


FIG. 45

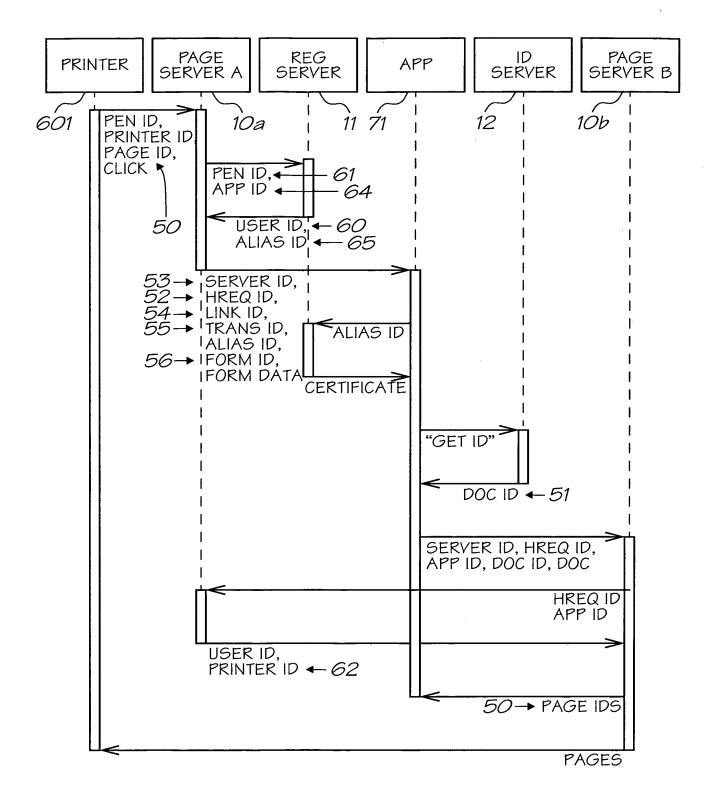


FIG. 46

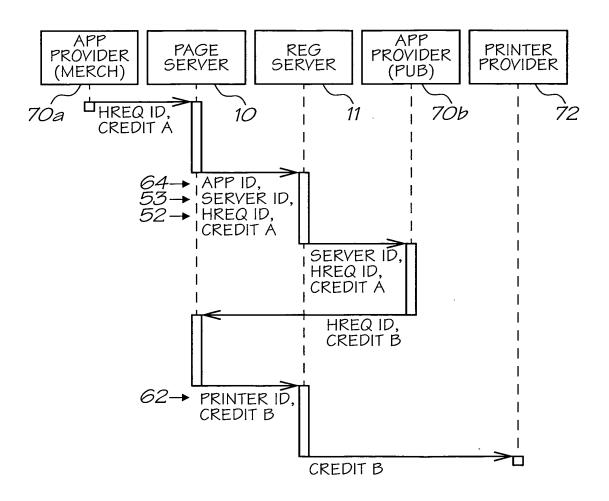
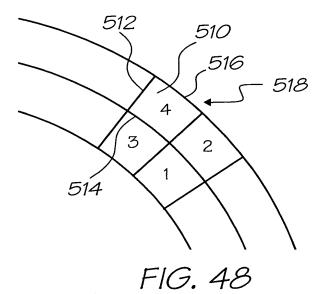


FIG. 47



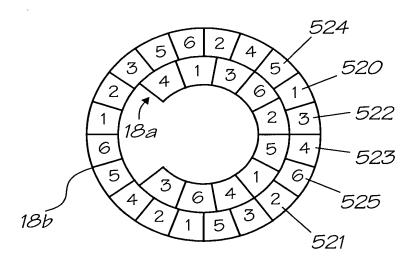


FIG. 49

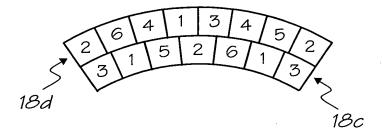


FIG. 50

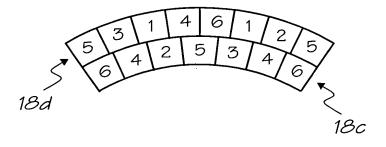


FIG. 51

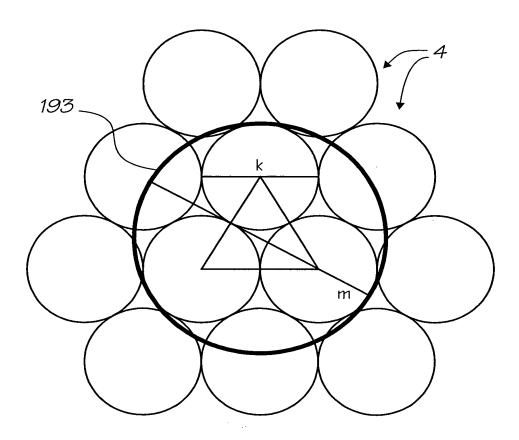


FIG. 52



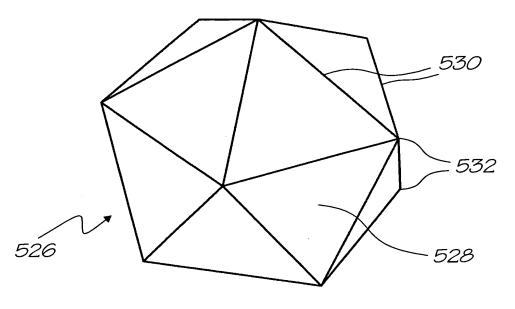


FIG. 53

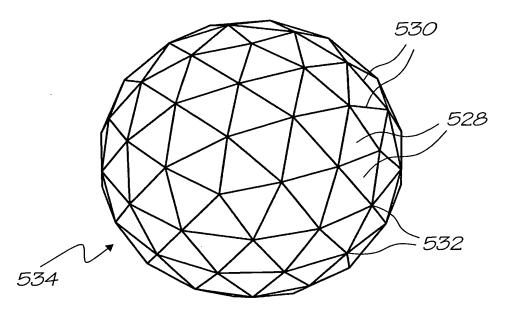


FIG. 54

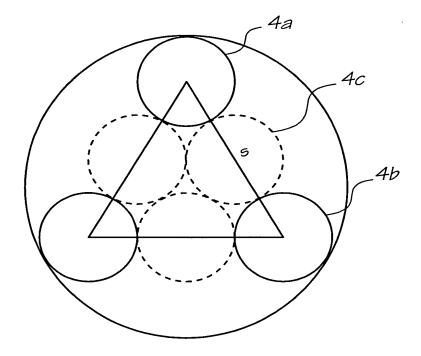


FIG. 55

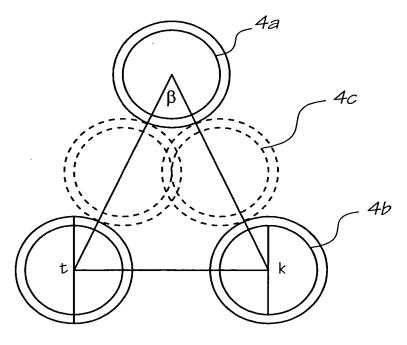


FIG. 56

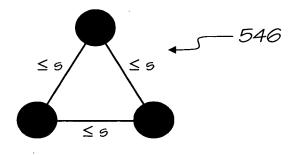


FIG. 57

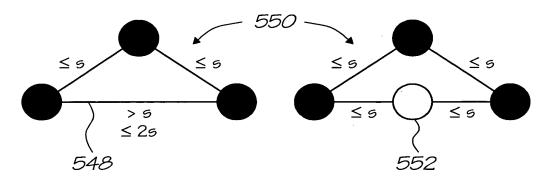


FIG. 58

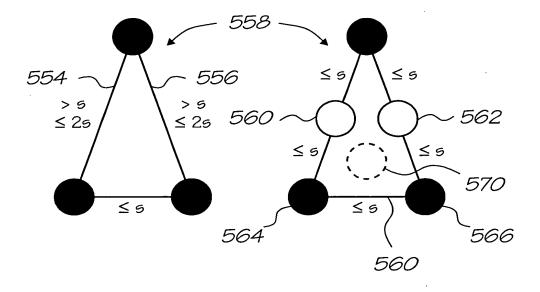


FIG. 59

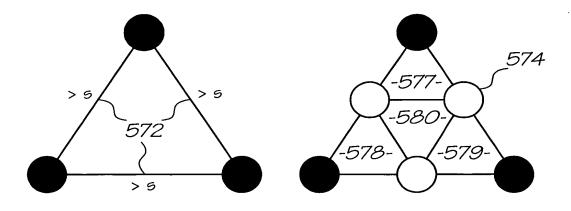


FIG. 60

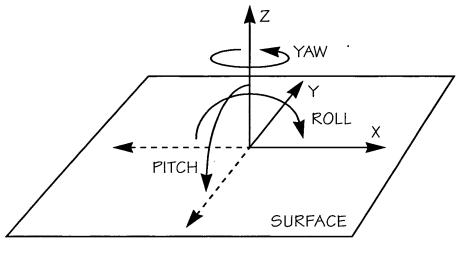


FIG. 61

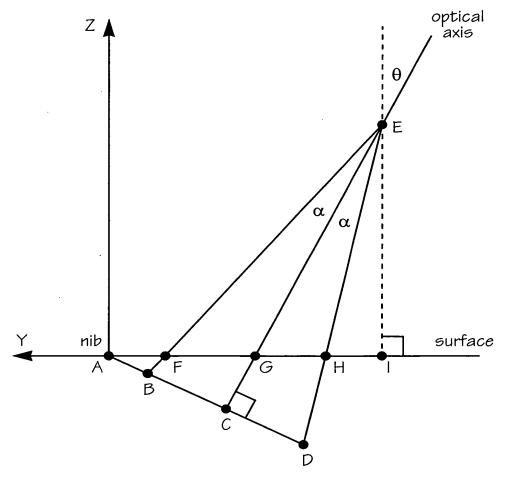


FIG. 62

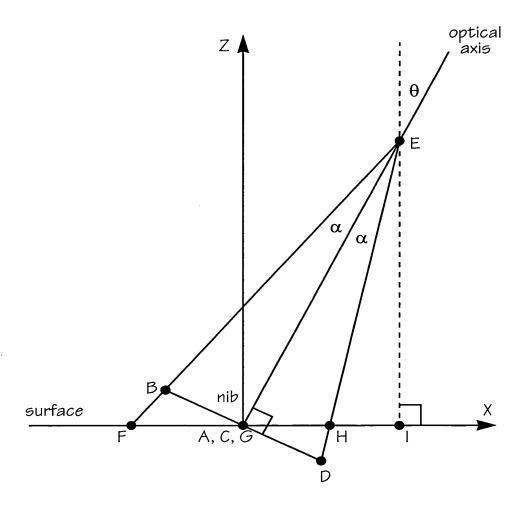


FIG. 63

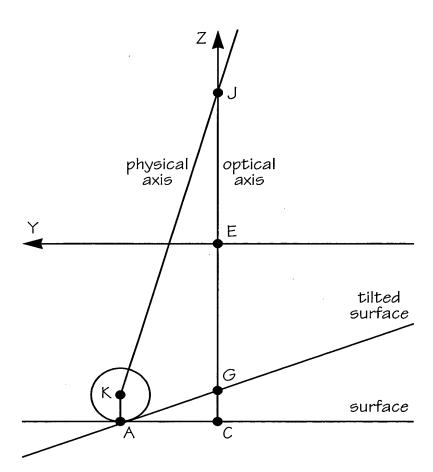


FIG. 64

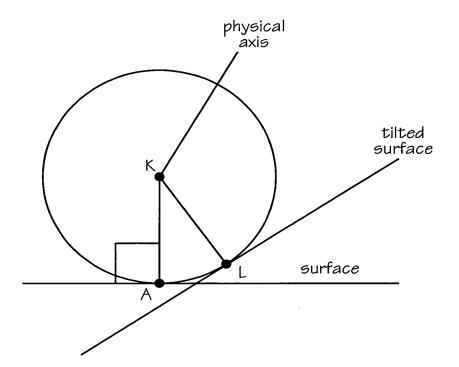


FIG. 65

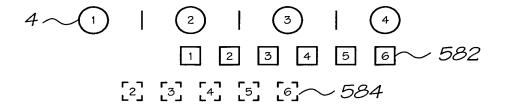


FIG. 66

EQ NUMBER	EQUATION
1	$m = k \left(\frac{2}{\sqrt{3}} + 1 \right)$
2	$m = \frac{2s}{\sqrt{3}} + k$
3	$u = k\left(\frac{2}{\sqrt{3}} - 1\right)$
4	$m = \frac{7k}{3}$
5	$\theta = 2\arcsin\left(\frac{2}{\sqrt{10+2\sqrt{5}}}\right) \approx 63.4^{\circ} \approx 1.11 \text{ radians}$
6	$n = 10v^2 + 2 = 10 \left[\frac{\theta r}{K} \right]^2 + 2$
7	$r \le \frac{K}{\theta} \left\lfloor \sqrt{\frac{n-2}{10}} \right\rfloor$
8	$s \ge 2k$
9	$\beta = 2\arcsin\frac{k}{2t}$
10	$s \ge 2t$

FIG. 67

EQ NUMBER	EQUATION
11	$\sin\theta = \cos\phi\cos\psi$
12	2D an lpha
13	$S = T + D \tan \alpha$
14	$d = D - S \tan \theta$
15	$d\cos\theta(\tan(\theta+\alpha)-\tan(\theta-\alpha))$
16	$d\cos\theta(\tan(\theta+\alpha)-\tan(\theta-\alpha))\geq m$
17	$\frac{d\cos\theta}{\cos(\theta + \alpha)}$
18	$\cos(\theta + \alpha)$
19	$\omega = \frac{fd\cos\theta}{\cos^2(\theta + \alpha)}$
20	$\omega_0 = \frac{fD}{\cos^2 \alpha}$

FIG. 68

EQ NUMBER	EQUATION
21	$q = 2\alpha' n\omega \cos^2(\theta' + \alpha')$
22	$q = \frac{2\alpha' n f d \cos \theta \cos^2(\theta' + \alpha')}{\cos^2(\theta + \alpha)}$
23	$q = \frac{2\alpha n f d \cos \theta \cos^2 \alpha}{\cos^2 (\theta + \alpha)}$
24	$q = \frac{2\alpha nfd}{\cos\theta (1 - \tan \theta \tan\alpha)^2}$
25	$q_0 = 2\alpha nfD$
26	$q = 2\alpha n f d \cos \theta$

FIG. 69

EQ NUMBER	EQUATION
27	$P_{sensed} = \begin{pmatrix} 0 \\ 0 \\ -d \end{pmatrix}$
28	$P_{pivot} = \begin{pmatrix} 0 \\ S \\ R - D \end{pmatrix}$
29	$\overrightarrow{V}_{pivot-sensed} = P_{pivot} - P_{sensed} = \begin{bmatrix} 0 \\ S \\ R - D + d \end{bmatrix}$
30	$\overrightarrow{N} = M \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$
31	$\overrightarrow{V}_{contact-pivot} = R \frac{\overrightarrow{N}}{ \overrightarrow{N} }$
32	$\overrightarrow{V}_{contact-sensed} = \overrightarrow{V}_{contact-pivot} - \overrightarrow{V}_{pivot-sensed}$
33	$\overrightarrow{V}_{contact-tag} = \overrightarrow{V}_{sensed-tag} + M^{-1} \overrightarrow{V}_{contact-sensed}$
34	$P_{contact} = P_{tag} + V_{contact - tag}$

FIG. 70

EQ NUMBER	EQUATION
35	$\gamma_{pen} = -\gamma_{tag}$
36	$\phi_{pen} = -\phi_{tag} - \phi_{sensor}$
37	$\psi_{pen} = -\psi_{tag}$
38	$\lambda_S < \frac{\lambda_T}{2}$
39	$P_{i+1} - P_i = \lambda_S$
40	$\left \lambda_T - (P_{i+1} - P_i)\right = \lambda_S$
41	$\lambda_S = \frac{\lambda_T}{2}$

FIG. 71

EQ				EQUATION	
42	$M_1 = T_{xy} = \begin{bmatrix} 1 & 0 & 0 & A \\ 0 & 1 & 0 & B \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$				
43	$R_z = \begin{bmatrix} C & -D & 0 & 0 \\ D & C & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$				
44	$M_2 = R_z M_1 = \begin{bmatrix} C \\ D \\ 0 \\ 0 \end{bmatrix}$	-D 0 0	0 0 1 0	AC - BD $AD + BC$ 0 1	

F1G. 72

ĺ			EQUATION	2	
0 0	$\begin{bmatrix} F & E & 0 \\ 0 & 0 & 1 \end{bmatrix}$				
:	2		0	AC-BD	
R		CE	-F	ADE + BCE	
×	$\frac{113}{2} = \frac{11}{2} = \frac{11}{2}$	CF	E	ADF + BCF	
	0	0	0		
\mathcal{S}	0				
0	1 0 0 G				
0]	0 0				

FIG. 73

EQ NUM	EQUATION
48	$M_4 = R_y M_3 = \begin{bmatrix} CG + DFH & CFH - DG & EH & GK + HL \\ DE & CE & -F & ADE + BCE \\ DFG - CH & DH + CFG & EG & GL - HK \\ 0 & 0 & 0 & 1 \end{bmatrix}$
49	K = AC - BD
50	L = ADF + BCF
51	$T_z = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & I \\ 0 & 0 & 0 & 1 \end{bmatrix}$

F1G. 74

EQ NUM			EQUATION		
52	$M_5 = T_z M_4 =$	$\begin{bmatrix} CG + DFH & CFH - DG \\ DE & CE \\ DFG - CH & DH + CFG \\ 0 & 0 \end{bmatrix}$	$egin{array}{cccc} -DG & EH \ E & -F \ CFG & EG \ \end{array}$	$egin{aligned} GK + HL \ ADE + BCE \ GL - HK + I \ 1 \end{aligned}$	
53	$M_p = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$			·	
54	$= {}^{2}M^{d}M = {}^{9}M$	$\begin{bmatrix} CG + DFH \\ DE \\ 0 \\ J(DFG - CH) \end{bmatrix}$	CFH - DG CE 0 $J(DH + CFG)$	EH -F 0 EGJ	GK + HL $ADE + BCE$ 0 $J(GL - HK + I) + 1$

FIG. 75

EQ NUM			EQUATION		
. 22	$M_s = \begin{bmatrix} S & 0 & 0 & 0 \\ 0 & S & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$				
56	$M_7 = M_S M_6 = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$	S(CG + DFH) SDE 0 $J(DFG - CH)$	S(CFH-DG) SCE 0 $J(DH+CFG)$	SEH -SF 0 EGJ	S(GK + HL) $S(ADE + BCE)$ 0 $J(GL - HK + I) + 1$
57	$P_1 = M_7 \begin{bmatrix} x \\ y \\ 0 \end{bmatrix}$				

F1G. 76

EQ NUM	EQUATION
28	$P_1 = \begin{bmatrix} S(CG + DFH)x + S(CFH - DG)y + S(GK + HL) \\ SDEx + SCEy + S(ADE + BCE) \\ 0 \\ J(DFG - CH)x + J(DH + CFG)y + J(GL - HK + I) + 1 \end{bmatrix}$
59	$P_{1} = \begin{bmatrix} S(CG + DFH)x + S(CFH - DG)y + S(ACG - BDG + ADFH + BCFH) \\ SDEx + SCEy + S(ADE + BCE) \\ 0 \\ J(DFG - CH)x + J(DH + CFG)y + J(BDH - ACH + ADFG + BCFG + I) + 1 \end{bmatrix}$

FIG. 77

EQ NUMBER	EQUATION
60	$M_{p2Dinf} = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & 1 \end{bmatrix}$
61	$M_{p2D} = \begin{bmatrix} ai \ bi \ ci \\ di \ ei \ fi \\ gi \ hi \ i \end{bmatrix}$
62	$P_2 = M_{per2D} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$
63	$P_{2} = \begin{bmatrix} aix + biy + ci \\ dix + eiy + fi \\ gix + hiy + i \end{bmatrix}$

FIG. 78

EQ NUMBER	EQUATION
64	$\frac{ai}{S} = CG + DFH$
65	$\frac{bi}{S} = CFH - DG$
66	$\frac{ci}{S} = ACG - BDG + ADFH + BCFH$
67	$\frac{di}{S} = DE$
68	$\frac{ei}{S} = CE$
69	$\frac{fi}{S} = ADE + BCE$
70	gi = J(DFG - CH)
71	hi = J(DH + CFG)
72	i = J(BDH - ACH + ADFG + BCFG + I) + 1
73	$\sin^2\theta + \cos^2\theta = 1$
74	$\theta = \arctan(\sin\theta, \cos\theta)$

FIG. 79

EQ NUMBER	EQUATION
75	$\frac{ci}{S} = A(CG + DFH) + B(CFH - DG)$
76	c = Aa + Bb
77	$\frac{fi}{S} = A(DE) + B(CE)$
78	f = Ad + Be
79	i = AJ(DFG - CH) + BJ(DH + CFG) + IJ + 1
80	i = Agi + Bhi + IJ + 1
81	$A = \frac{c - Bb}{a}$
82	$A = \frac{f - Be}{d}$
83	$\frac{c - Bb}{a} = \frac{f - Be}{d}$
84	cd - Bbd = af - Bae
85	B(ae-bd) = af-cd
86	$B = \frac{af - cd}{ae - bd}$

FIG. 80

EQ NUMBER	EQUATION
87	$A = \frac{f - \left(\frac{af - cd}{ae - bd}\right)e}{d}$
88	$A = \frac{f(ae - bd) - e(af - cd)}{d(ae - bd)}$
89	$A = \frac{aef - bdf - aef + cde}{d(ae - bd)}$
90	$A = \frac{-bdf + cde}{d(ae - bd)}$
91	$A = \frac{-bf + ce}{ae - bd}$
92	$C = \frac{ei}{ES}$
93	$D = \frac{di}{ES}$
94	$a = \frac{e}{E}G + \frac{d}{E}FH$
95	$b = \frac{-d}{E}G + \frac{e}{E}FH$
96	$g = \frac{-e}{ES}H + \frac{d}{ES}FG$
97	$h = \frac{d}{ES}H + \frac{e}{ES}FG$
98	$E = \frac{eG + dFH}{a}$
99	$E = \frac{-dG + eFH}{b}$

FIG. 81

EQ NUMBER	EQUATION
100	$ES = \frac{-eH + dFG}{g}$
101	$ES = \frac{dH + eFG}{h}$
102	$\frac{eG + dFH}{a} = \frac{-dG + eFH}{b}$
103	$\frac{FH}{G} = \frac{ad + be}{ae - bd}$
104	$\frac{-eH + dFG}{g} = \frac{dH + eFG}{h}$
105	$\frac{FG}{H} = \frac{dg + eh}{dh - eg}$
106	$\frac{FH}{G} \times \frac{FG}{H} = \frac{(ad+be)(dg+eh)}{(ae-bd)(dh-eg)} = F^2$
107	$F = \pm \sqrt{\frac{(ad+be)(dg+eh)}{(ae-bd)(dh-eg)}}$
108	$E = \pm \sqrt{1 - F^2}$
109	$\phi = \arctan(E, F)$
110	$\frac{1}{F} \times \frac{FH}{G} = \frac{H}{G} = \left(\pm \sqrt{\frac{(ae - bd)(dh - eg)}{(ad + be)(dg + eh)}}\right) \times \frac{(ad + be)}{(ae - bd)}$
	$= \pm \sqrt{\frac{(ad+be)(dh-eg)}{(ae-bd)(dg+eh)}}$
111	$\frac{H}{G} = \frac{H}{\pm \sqrt{1 - H^2}} = \frac{1}{\pm \sqrt{\frac{1}{H^2} - 1}}$

FIG. 82

EQ NUMBER	EQUATION
112	EQUATION $H = \frac{1}{\pm \sqrt{\left(\frac{H}{G}\right)^2 + 1}}$
113	$G = \pm \sqrt{1 - H^2}$
114	$\psi = \arctan(G, H)$
115	$\left(\frac{ei}{ES}\right)^2 + \left(\frac{di}{ES}\right)^2 = 1$
116	$\frac{S}{i} = \frac{\pm \sqrt{d^2 + e^2}}{E}$
117	$C = \frac{e}{E} \times \frac{E}{\pm \sqrt{d^2 + e^2}}$
118	$C = \frac{e}{\pm \sqrt{d^2 + e^2}}$
119	$D = \frac{d}{E} \times \frac{E}{\pm \sqrt{d^2 + e^2}}$
120	$D = \frac{d}{\pm \sqrt{d^2 + e^2}}$

FIG. 83

EQ NUMBER	EQUATION
121	i(1 - Ag - Bh) = IJ + 1
122	sign(i) = -sign(1 - Ag - Bh)
123	$\gamma = \arctan(D, C)$
124	$S = \frac{di}{DE}$
125	$S = \frac{ei}{CE}$
126	$sign(FH) = sign\left(\frac{ad + be}{ae - bd}\right)$
127	$J = \left \frac{gi}{-CH + \operatorname{sign}(FH)DFG} \right $
128	$J = \left \frac{hi}{DH + \text{sign}(FH)CFG} \right $
129	$I = \frac{(i - Agi - Bhi - 1)}{J}$

FIG. 84

hi	0	0	0	±FJ	0	CFJ	0	∓HJ	DHJ	±FGJ	∓HJ	DHJ+ CFGJ	
				•			(r						$\left. \right $
gi	0	0	0	0	±FJ	DFJ	(∩H-)∓	0	HQ-	(∩H-)∓	±FGJ	-CHJ+ DFGJ	
fi	SB∓	SYŦ	SB	Bei	Adi	Adi+Bei	SB∓	∓AS	Adi+Bei	Bei	Adi	Adi+Bei	
ei	SŦ	0	SO	S∃∓	0	CES	SŦ	0	SO	S∃∓	0	CES	
qi	0	SŦ	SO	0	∓ES	DES	0	SŦ	DS	0	ŦES	DES	
. <u>2</u>	#AS	∓(-BS)	Aai+Bbi	∓AS	(S8-)∓	Aai+Bbi	Aai	Bbi	Aai+Bbi	Aai+Bbi	Aai+Bbi	Aai+Bbi	
Ď	0	∓(-S)	SO-	0	∓(-S)	SO-	0	∓(-GS)	-DGS	∓FHS	∓(-GS)	-DGS+	
<u>.</u>	S T	0	SO	SŦ	0	SO	∓GS	0	SSO	∓GS	∓FHS	CGS+ DFHS	
ĞН	1,0	1,0	1,0	1,0	1,0	1,0	G,H	G,H	G,H	G,H	G,H	G'H	
Щ Щ	1,0	1,0	1,0	П	E,F	E,F	1,0	1,0	1,0	H,	E,F	П П	
C,D	±1,0	0,±1	C'D	±1,0	0,±1	a's	±1,0	0,±1	C,D	±1,0	0,±1	C,D	
case	1a	1b	10	2a	2b	2c	3a	39	သွ	4a	4b	4c	

FIG. 85

1 2a	g = h = 0	$E \leftarrow 1$ $F \leftarrow 0$ $G \leftarrow 1$ $H \leftarrow 0$
		$G \leftarrow 1$
2a		
2a		$H \leftarrow 0$
2a		
	b = d = g = 0	4
:		$E \leftarrow \frac{e}{a}$ $\frac{FJ}{S} = \frac{h}{a}$
		FI h
		$\frac{10}{S} = \frac{n}{a}$
		, S
2b	a = e = h = 0	_d
		$E \leftarrow \frac{-a}{b}$
		$E \leftarrow \frac{-d}{b}$ $\frac{FJ}{S} = \frac{-g}{b}$
	_	$\frac{10}{S} = \frac{8}{b}$
2c	a - h	
	$\frac{a}{b} = \frac{\pi}{\varrho}$	handle via 2a or 2b
	• 0	
2		$G \leftarrow 1$
		$H \leftarrow 0$
		$(F.I) \int_{-\infty}^{\infty} 2$
		$F \leftarrow \operatorname{sign}\left(\frac{FJ}{S}\right)\sqrt{1-E^2}$
	2b 2c 2	$\frac{a}{b} = \frac{-h}{g}$

FIG. 86

description	case	condition	handling
zero pitch	3a	b = d = h = 0	$G \leftarrow \frac{a}{e}$ $\frac{HJ}{S} = \frac{-g}{e}$
	3b	a = e = g = 0	$G \leftarrow \frac{-b}{d}$ $\frac{HJ}{S} = \frac{h}{d}$
	Зс	$\frac{a}{b} = \frac{g}{h}$	handle via 3a or 3b
	3	·	$E \leftarrow 1$ $F \leftarrow 0$ $H = \operatorname{sign}\left(\frac{HJ}{S}\right)\sqrt{1 - G^2}$
non-zero pitch & non-zero roll	4	$(g \neq 0) \land (h \neq 0)$	handle via general solution

FIG. 87